

New Methods to Predict Distortions in Automotive Gears

In a US industry effort to improve metal manufacturing techniques for products such as automotive gears, Los Alamos and three other national laboratories have joined the National Center for Manufacturing Sciences in a cooperative venture to address the problem of heat treatment distortion.



The complex geometry of gears makes it particularly challenging to predict how and where distortions will occur during the heat treatment process.

The Problem

The US automobile industry uses heat treatment to create strong, hard, metal parts such as gears, shafts and rotors. This process causes the part to distort unpredictably, costing the auto industry an estimated \$230 million annually in added costs to correct for distortion of transmission gears, alone.

A computer simulation tool is needed that can predict how the parts will distort. Such a tool would reduce the number of parts that don't meet specifications by allowing manufacturers to adjust the process to compensate for the distortions.

The Success

The National Center for Manufacturing Sciences (NCMS) is leading an effort to solve the heat treatment distortion problem. Many NCMS members, including General Motors, Ford Motor Co., and the Torrington Company are working together on the project. Los Alamos National Laboratory materials scientist, Terry Lowe, helped NCMS put together a large group of talent

"I think this is an outstanding example of how the technical capabilities of the national laboratories can blend with industry to really make a difference"—John DeCaire, President, NCMS.

from Los Alamos, Oak Ridge, Sandia, and Lawrence Livermore National Laboratories to address the variations in the heat treatment process and to design a predictive simulation tool based on the success of earlier quench simulator efforts at Oak Ridge, which simulated uranium alloy heat treatment distortion. The parties signed a \$24.3 million cooperative research and development agreement (CRADA), and the teams began experimentation and characterization of heat-treated chromium alloy steels. There are ten task driven technology teams on the project; Los Alamos contributes to six of these, applying expertise in measurement of residual stress, measurement of elastic properties, characterization of phase transformations, constitutive

modeling, numerical analysis, and finite element analysis.

The project will be ongoing over the next couple of years, but there have already been significant milestones in the work. For instance, the teams have successfully modeled the heat treatment process, including the effects of the metallurgical processes that actually cause distortion and residual stresses. This is a crucial step toward helping US manufacturers pull ahead of their foreign competitors in the race toward technical excellence in manufacturing. This success is the basis for enhancements to the

National Center for Manufacturing Sciences-NCMS

Located in Ann Arbor, Michigan, the NCMS originally was founded by the machine tool industry to advance the manufacturing capability of US companies, and enhance their global competitiveness.

NCMS members include small- and medium-sized shops, as well as a who's who of manufacturing and equipment companies including GM, Ford, AT&T, Eastman Kodak, Ingersoll-Rand, and Rockwell International.

INDUSTRIAL PARTNERSHIP SUCCESS - CRADA

A Defense Programs Technology Transfer Initiative Project

predictive tools that are currently under development.

The Technology

Heat treatment is performed by heating a gear to a very high temperature in a furnace and then rapidly cooling (quenching) it in an oil bath. This changes the microstructural properties of the metal from a relatively soft state—where it can be shaped—into a very hard state that is more suitable for the kind of wear a gear is subject to as part of an automobile transmission. The gear is made of a metal alloy that expands and contracts nonuniformly during different parts of this transformation. This makes it difficult to predict the final shape of each gear. In addition, the microstructural properties of the metal before treatment are not uniform throughout, making the distortions nonuniform, and the rapid expansion and contraction of the metal creates residual stresses within the gear. These stresses may reduce gear lifetime, cause premature failure, or generate noise and vibration.

Some of the numerous factors that need to be taken into consideration in order to make accurate predictions are variations in the steel alloy being used, temperature of both the furnace and the cooling bath, number of parts in a bath, size of the bath, and amount of time the gear is in the heating or cooling part of the process.

The Applications

US automotive gear manufacturers will use this tool to redesign their heat treatment processes and equipment. Additional industrial applications include aerospace engines, transmissions, bearings, and structures; marine engines and drives; agricultural equipment; construction equipment; oil and chemical processing pumps and gear boxes;

military vehicles; mining machinery; earth moving equipment; appliances; power tools; and automotive aftermarkets.

The Product

The final result of the CRADA will be a computer code that engineers can use to predict the effects of heat treatment on residual stresses found in and/or the size and shape of industrial parts made out of heat-treated metal alloys.

Benefits To NCMS Members

NCMS is a non-profit R&D consortium of North American manufacturing companies. NCMS tool user and provider members will benefit from access to improved techniques and products. By reducing the cost to gear manufacturers and customers, this technology may well save US industry billions of dollars in wasted hours, manpower, and materials.

Benefits To DOE

Of the hundreds of unique components contained in typical nuclear weapons systems, most of the wrought metal parts undergo thermal processing or welding. These processes induce residual stresses and distortion. With only a few exceptions, computational modeling has not been used to predict these effects in nuclear weapons manufacture. The computational tool developed in this CRADA can be used to make improvements in manufacture of nuclear weapons components, reducing waste and increasing reliability.

The national laboratories have several areas of expertise that stand to benefit from this project, including high-performance computing and simulation, numerical code development and application,

Automotive Parts Industry

Financial pressures on parts suppliers have greatly increased as their customers often ask them to finance R&D, inventory, tooling, and logistics.

In recent years, increasingly severe competition has taken its toll on domestic profits. It also has propelled the industry on a painful, but beneficial, journey to reduce operating expenditures through improvements in manufacturing technology and productivity and reductions in overhead expenses.

constitutive relations development, cutting-edge material characterization capabilities, material characterization by neutron scattering, and precision engineering and inspection. Finally, the successful demonstration of this highly sophisticated manufacturing process model will benefit all areas of the DOE complex in which numerical process models and methodologies can be employed.

Future Plans/Applications

Experimentation and documentation must continue until there is enough information in the model to allow for accurate predictions. NCMS manufacturer members plan to use the simulator in refining their heat treatment processes and as a product design tool.

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